GE
Transportation

Hybrid

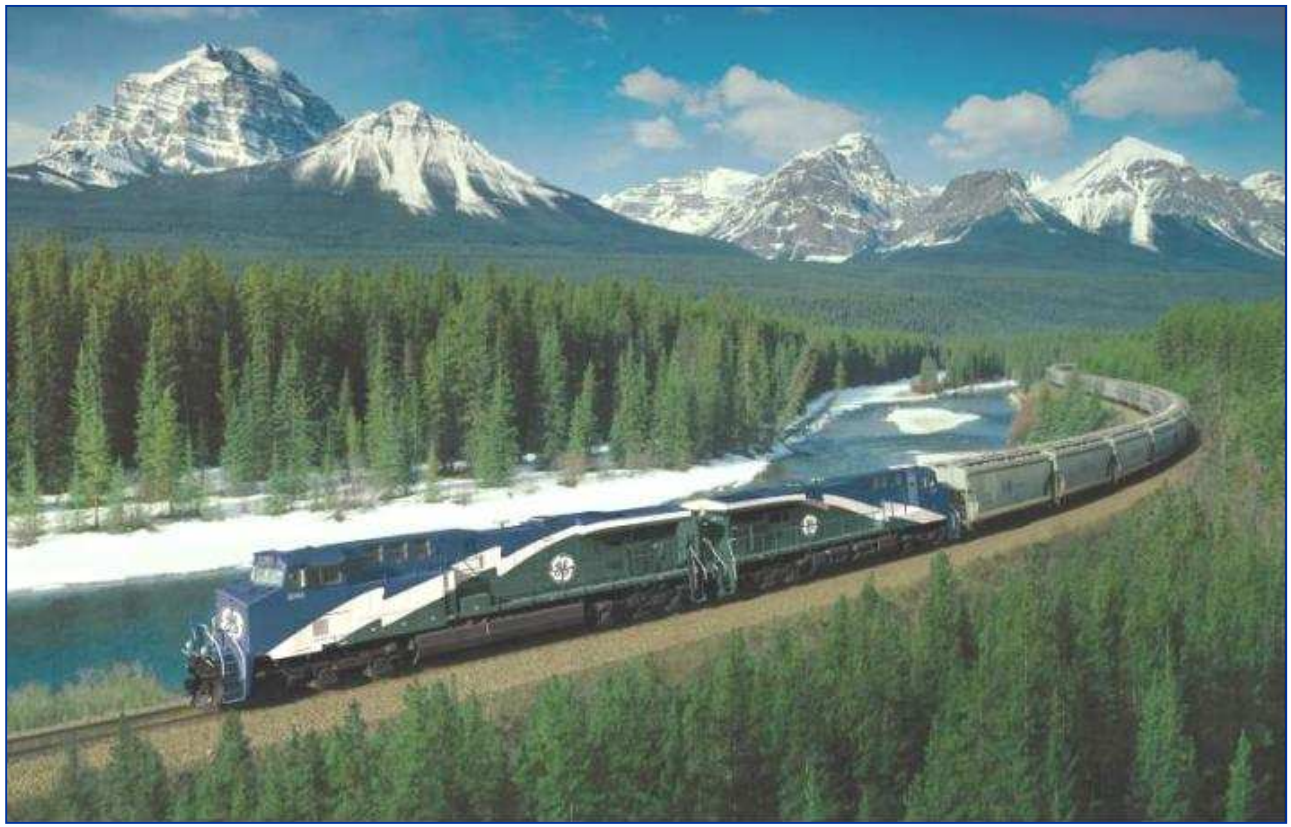
On the main line

CARB
November 28, 2007

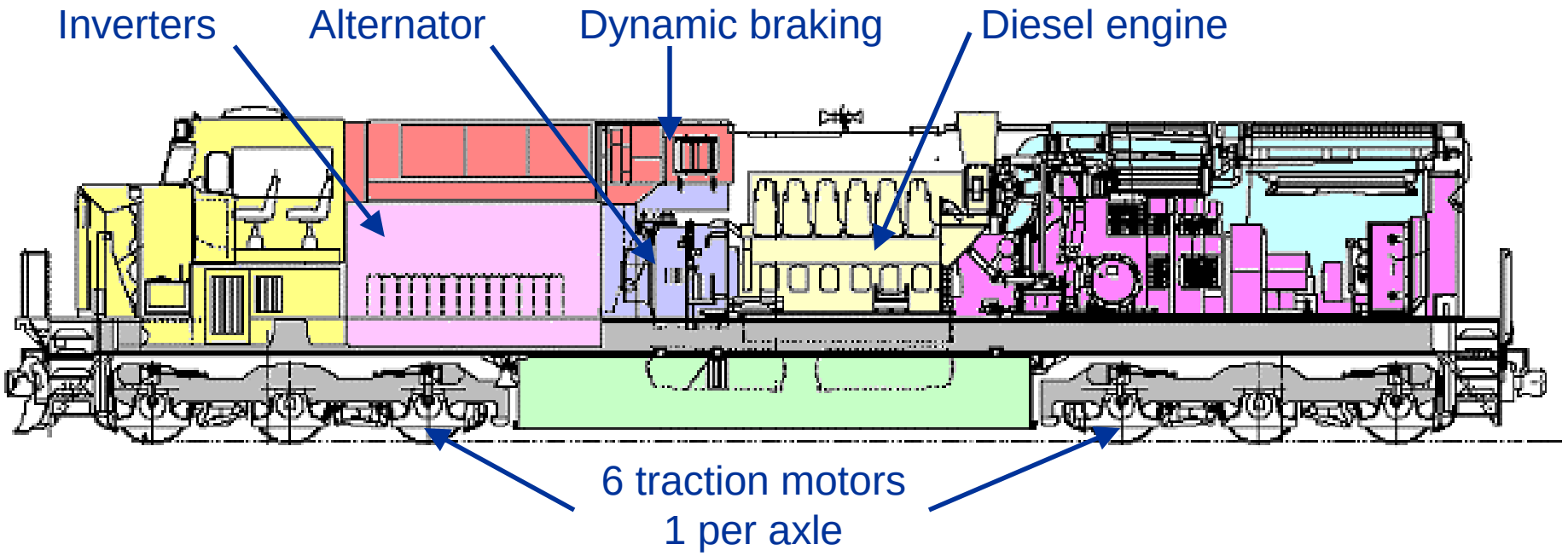
a product of
ecomagination

Can hybrid technology work to reduce emissions and improve fuel efficiency of the North American heavy-haul diesel electric freight locomotive

W think the answer is . . . YES



Heavy-haul diesel-electric freight locomotive

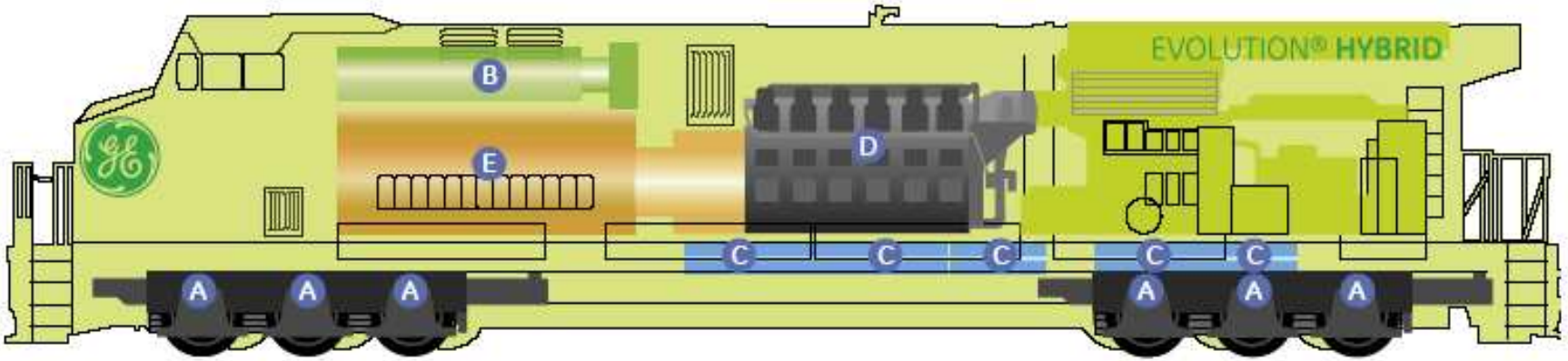


- Series-electric transmission
- 4,500 HP in motoring & 5,400 HP in dynamic braking
- ~8,760 operating hr/yr
- 20+ year design life
- 210 t

Evolution Series® Hybrid

The Evolution Hybrid stores power utilized from dynamic braking to supplement the diesel-electric engine, thereby reducing emissions & fuel consumption by up to 10%

How it works



How it works

In a conventional locomotive, energy generated by the traction motors (A) during braking is dissipated entirely as heat through resistor grids (B).

In contrast, in a hybrid locomotive, some of that energy is captured in a series of lead-free, rechargeable batteries (C).

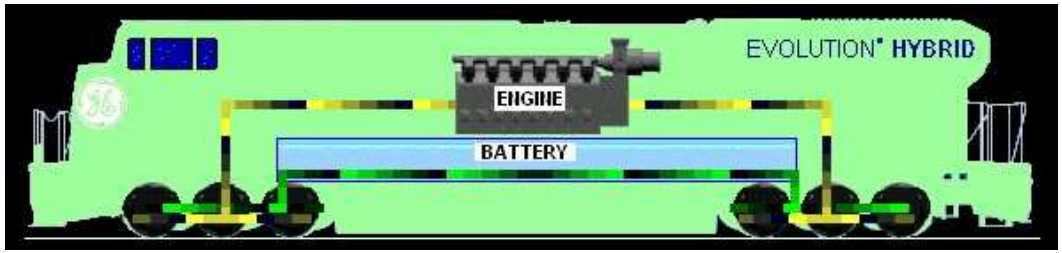
The captured energy can then be used to provide power in one of three ways:

- In combination with diesel-electric power (provided by the engine (D) and the electrical system (E)) to consistently deliver the required horsepower.
- As an addition to full diesel-electric power for quick acceleration from a full stop.
- As the primary power source (full battery power).

Modes of operation

Hybrid power mode

Hybrid Power Mode allows the locomotive to use the stored energy in the batteries to supplement the diesel-electric engine. This allows the locomotive to conserve fuel by reducing the amount of output required from the diesel-electric engine

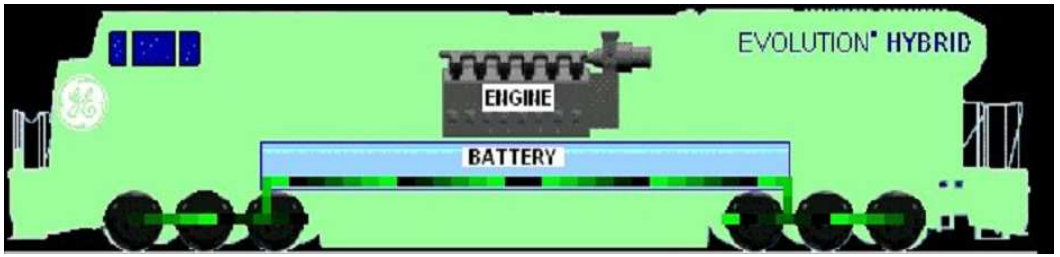


Power boost

Power boost allows for the batteries to be used in conjunction with the full 4400 hp power of the diesel-electric engine.

Primary power

In areas with restrictive emission zones, the Evolution Hybrid can use the power stored by batteries as the primary source of power reducing emissions and fuel consumption



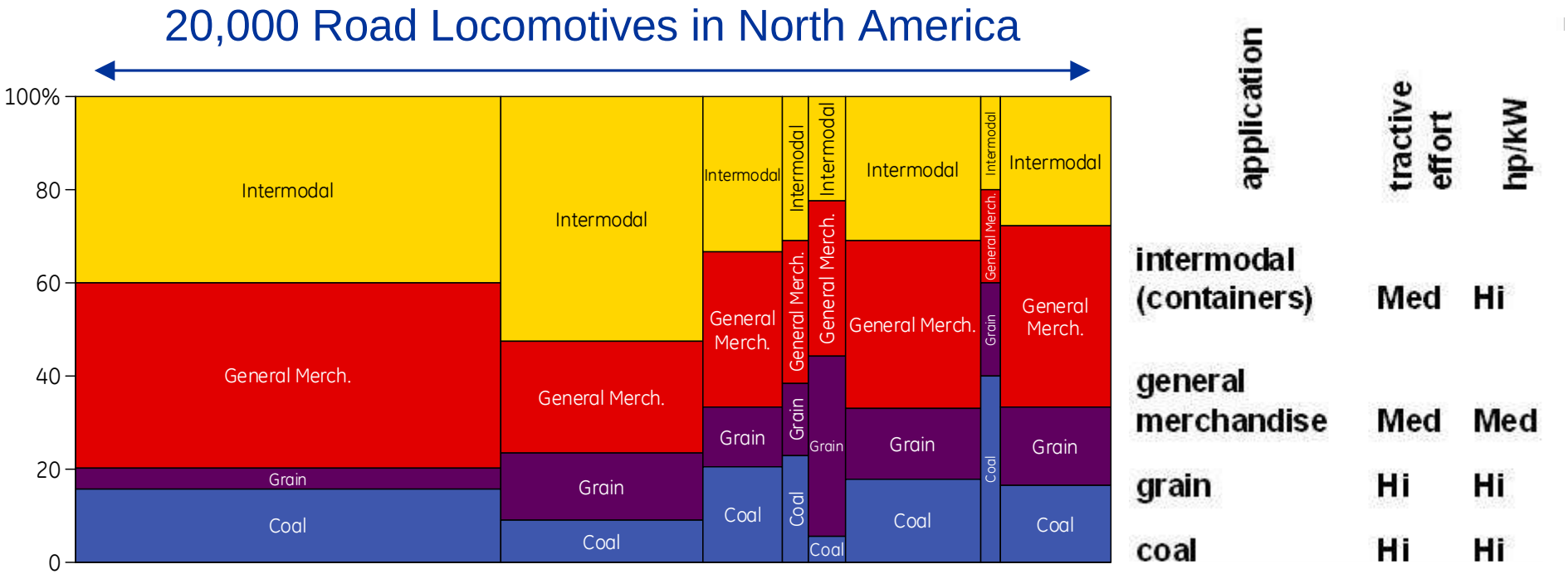
What is the significance

- ~ 20,000 road locomotives in North America
- Over 1,500 billion ton-miles freight per year
- Over 40% total freight movement
- Highly efficient: 400 ton-miles/gal (155 t-km/L)
- Over 4 billion gallons of diesel fuel per year
- 2.5% national fuel usage
- ~ 320,000 gallons/loco/year

10% fuel usage reduction

- ✓ Hybrid Evolution Loco vs a typical Tier 0
- ✓ 32,000 gallons fuel
- ✓ 357 tons CO_2
- ✓ 3.68 tons NOx

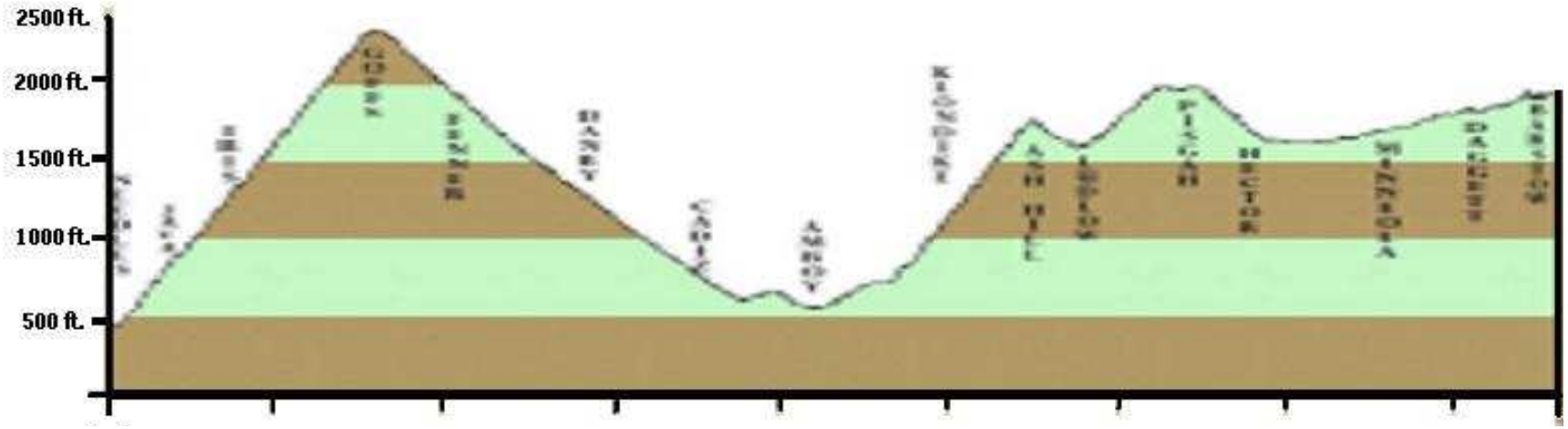
Understanding the potential



- Bulk haul: lower speeds, 0.75 to 2.0 HP/ton
- Intermodal: higher speeds, 3.0 to 10.0 HP/ton
- 900 miles average haul distance

Hybrid example

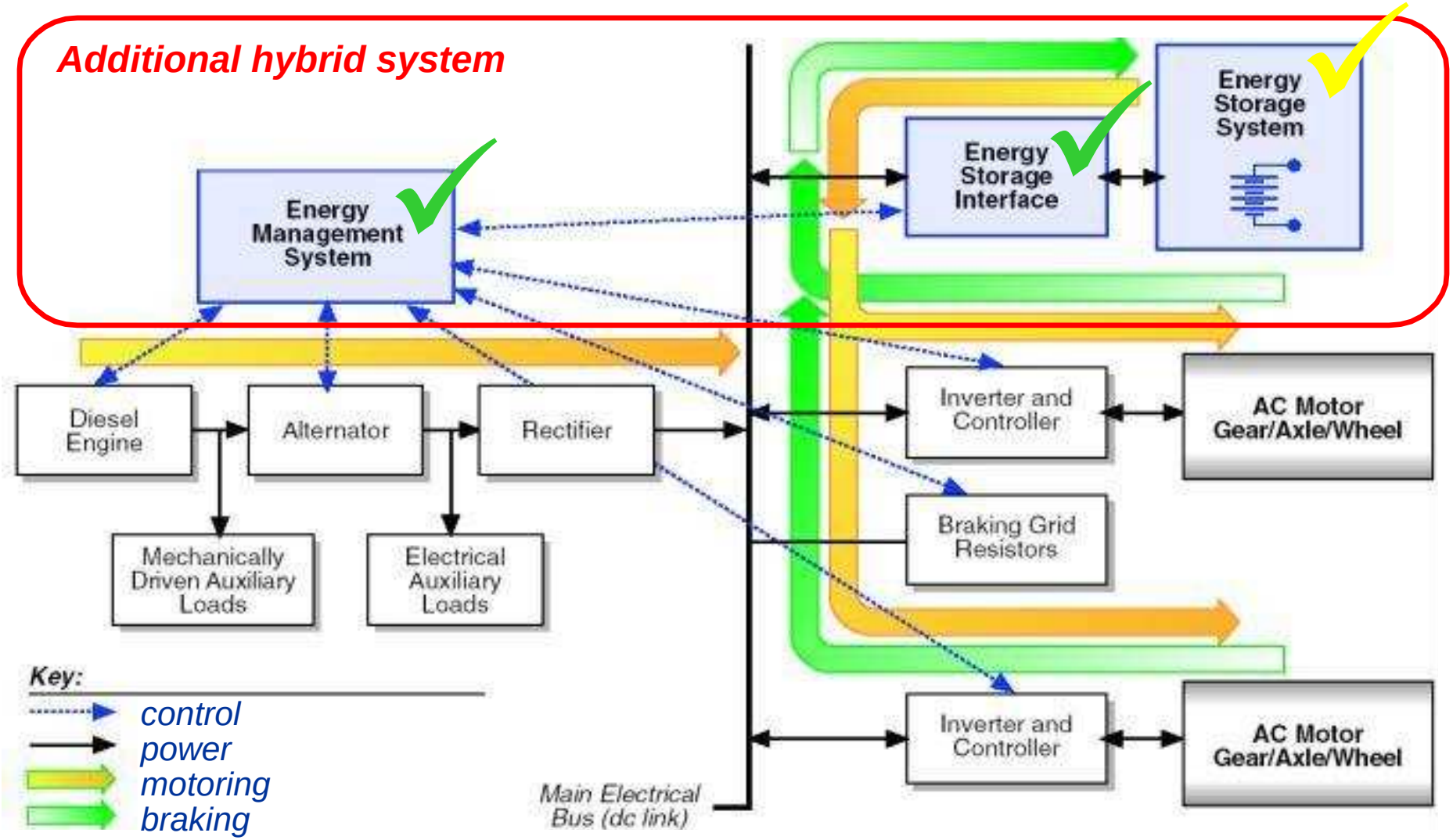
Locomotive saves fuel by substituting engine MWh with battery MWh



Typical Coal Run

Mileage	3,084
Hours	233
Gross Engine HPhr	155,239
DB HPhr Captured	14,455
Energy Savings	9.3%
DB Captured	~30%

Locomotive hybridization



Demanding energy storage requirements

Performance Requirement

- ~1,750 hp (1300 kW) continuous charge/discharge power
- ~1,000 kWh useable energy
- High utilization
- Drive cycles: supply and receive high power for minutes to hours

Mechanical and Environmental

- Ambient temperature specification - 40C to +55C
- Locomotive shock arising from train coupling buff forces
- Vibration resulting from heavy duty diesel and steel wheel-rail
- Weight and volume constraints

Life

- 20 year useful life (any combination of storage or service)

Current battery assessment

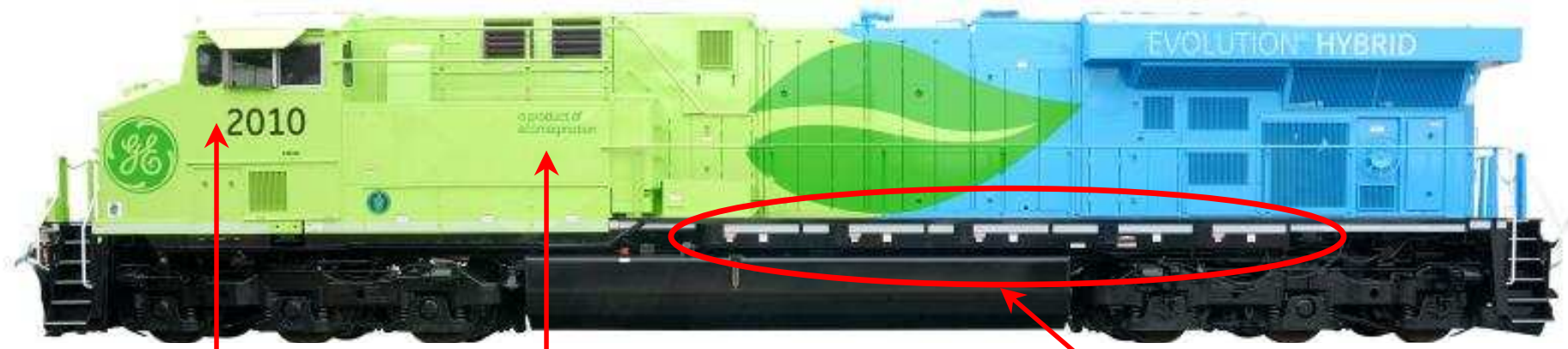
GE sodium based battery technology

Short-medium term assessment

- Battery weight
- Battery volume
- Operating temperature vs environment
- Cooling medium & technique *forced-air cooling very desirable: key factor*
- Energy loss per cell failure: *failure mode is short-circuit*
- Locomotive-robust package
- Expected price in production

Moving from the lab to the field

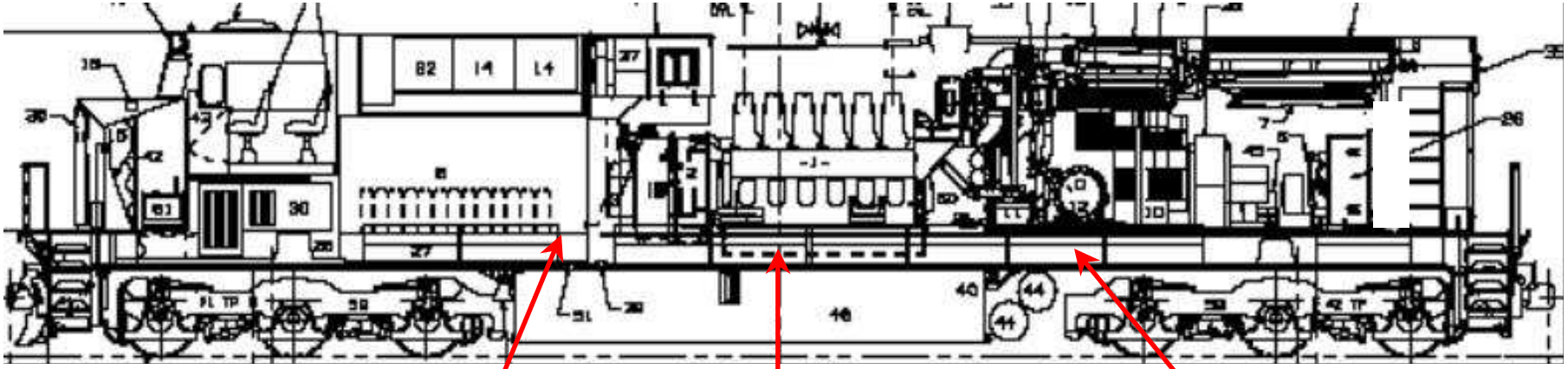
Demonstrator hybrid loco modifications



Energy mgmt system

Energy storage interface

Batteries under walkway



Raised walkway

Piping and cabling inside plenum

Lighter & longer platform

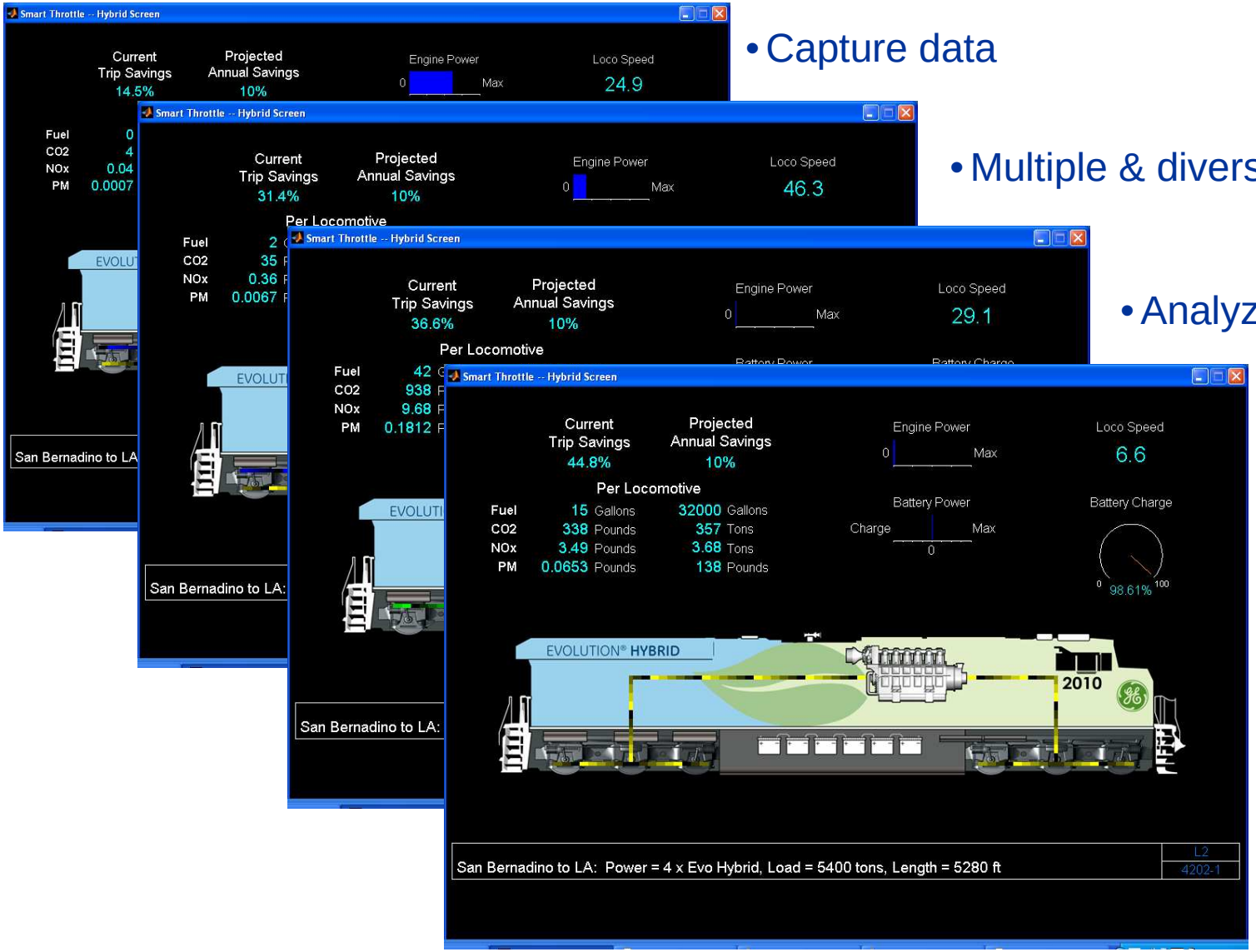
Roll out

Evolution Series® Hybrid Loco Demonstrator

GE ecomagination launch
Los Angeles Union Station - May 24, 2007

- ✓ Proof of concept
- ✓ Configuration validation
- ✓ Battery packaging
- ✓ Test track & field test bed

Experience in the real world



- Capture data
- Multiple & diverse applications
- Analyze performance
- Refine perf. Model
- Reliability validation
- Operational impact
- Service impact

GE hybrid program . . . More then just locomotives

Hybrid truck system validation

Validate system performance

- ✓ Fuel Savings
- ✓ Productivity
- ✓ Driveability
- ✓ Model Validation

Gain on-truck experience

- ✓ Reliability
- ✓ Shock & Vibration
- ✓ Dust

Challenges still remain

- Cost of batteries
- Hardening battery for rail application
- Packaging batteries within envelope of locomotive
- Managing weight to stay within infrastructure constraints
- Instilling new procedures & protocols to handle high voltage batteries
- Quantifying emissions benefits
- Develop process for recognition of emissions reductions

Next steps

- Battery
  - Vibration hardening
  - Bench evaluation & validation
  - Case development
  - On loco validation
  - Manufacturing development
- 2nd generation prototype locomotive
- Field validation
- Production launch

imagination at work